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NAVAL AIR PROPULSION TEST CENTER

TRENTON, NEW JERSEY 08628

NAPTC-PE-102 MAY 1977

NAPTC FACILITY MODIFICATIONS REQUIRED FOR ALTITUDE TESTING OF CURRENT V/STOL ENGINES

BY JOSEPH F. BOYTOS

&

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Modifications were made to NAPTC altitude chamber 3E to provide the capability to test current V/STOL aircraft engines. A test program was conducted with a F402 vectored-thrust turbofan engine to evaluate the modifications and verify facility operational capability.

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NAVAL AIR PROPULSION TEST CENTER
Trenton, New Jersey 08628

PROPULSION TECHNOLOGY AND PROJECT ENGINEERING DEPARTMENT

NAPTC-PE-102 MAY 1977

NAPTC FACILITY MODIFICATIONS REQUIRED FOR ALTITUDE TESTING OF CURRENT V/STOL ENGINES

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

Currently, the Naval Air Propulsion Test Center (NAPTC) is the only Naval facility having a range of capability to test turbojet/turbofan and turboprop/turboshaft engines, and helicopter transmissions under sea level, altitude and environmental conditions. The NAPTC was directed to modify and check-out an existing altitude and sea level test cell to provide the facility capability to test V/STOL aircraft engines (references 1, 2 and 3).

Decisions have been made to move toward development of vertical/short takeoff and landing (V/STOL) aircraft for deployment on board conventional large aircraft carriers, smaller ships down to frigate size, and vertical support ships as they enter the fleet in future years. Test requirements of a Lift/Cruise General Specification will be met by utilizing several types of facilities. Sea level cells, altitude chambers and special outdoor stands will be needed.

In order to provide cost-effective V/STOL engine test facilities, existing sea level and altitude chambers must be modified. Modifications to a NAPTC altitude chamber and sea level cell were required to keep pace with the Navy's "new look" with regard to reliability and maintainability in order to test, analyze and fix engine problems in the laboratory and not in the fleet. One approach, therefore, toward obtaining more reliable engines is through appropriate tests in facilities where the actual flight environment and mission profiles of the weapons system can be simulated.

Modifications to NAPTC altitude chamber 3E were completed in FY 1976 and a test program to evaluate facility characteristics was conducted using an F402 vectored-thrust engine as the test vehicle. Overall facility capability/engine operation was rated satisfactory. This report summarizes the altitude program effort. The sea level program is currently in progress and will be completed in FY 1977.

CONCLUSIONS

1. Steady-state and transient operation of V/STOL engines can be satisfactorily accomplished in altitude chamber 3E if the engine operating envelope is within the capacity of the plant equipment. (NOTE: All tests were run with the exhaust nozzles locked in the horizontal position).

2. An accurate determination of horizontal thrust can be made in 3E altitude chamber using a four-poster type V/STOL engine.

RECOMMENDATIONS

1. Design of the exhaust duct collector system should be optimized to improve the capacity of the exhauster system.

DISCUSSION

A. DESIGN APPROACH

1. Design Criteria

In order to test V/STOL aircraft engines, modifications were required to the 3E altitude chamber. Visits were made to the Rolls-Royce facility in Bristol, England - the engine manufacturer - and the Naval Air Rework Facility (NARF) at Cherry Point, NC, to inspect and analyze their V/STOL engine test installations and to become familiar with test techniques. Both of these facilities utilize large exhaust gas collector ducts in sea level test cells. Each exhaust nozzle gas stream is individually ducted to a large collector duct. Space limitations in the NAPTC 3E altitude chamber necessitated a compact installation.

The NAPTC design goals included the following criteria:

a. Design for a four-poster engine configuration (e.g., the F402 engine)

b. No interaction between the four exhaust nozzles which would affect engine performance

c. Maintain all four exhaust nozzles at the same simulated altitude pressure

d. Collect individual exhaust gas streams into a common exhaust duct

e. The exhaust collector duct system should not affect engine thrust

f. Cell ambient temperatures maintained below 125°C(257°F)

g. The inlet air supply system should provide a flat velocity profile to the engine

h. The compressor bleed systems must not structurally load the engine

i. Bleed air discharge must not interact with engine thrust measurement

j. Design the engine test stand so that neither the complete stand nor any of its members had a natural frequency in the engine operating range.

2. Exhaust Collector Duct System

A conventional turbojet engine has a single exhaust nozzle. When installed in an altitude cell, the exhaust nozzle discharges into a circular gas collector duct. This duct is connected to the exhausters that provide the simulated altitude pressure. One of the major problems in testing a four-poster V/STOL engine is collecting and discharging the exhaust gases. With different temperatures, velocities and airflows from the two hot and two cold nozzles, a gas collector system had to be designed to provide the same "altitude" at all four nozzles.

The final design, illustrated in Figure 1, incorporated a gas collector system that ducted the air individually from the forward nozzles (Sec. A-A) to a cylindrical duct aft of the engine. The design utilized two exhaust gas collectors, one on each side of the engine. The collector, which started at the cold nozzle, was rectangular in shape. As it progressed aft, the gas collector assumed a semi-circular shape until it reached a point 3.66m(12 ft) downstream of the engine where both collectors joined into a full cylindrical duct. The inner walls of the forward nozzle ducts formed the collector duct for the aft nozzles (Sec. B-B & C-C). At the point where the exhaust ducting became cylindrical by bringing the two collectors together, the cold and hot gases were discharged into the ducting that is connected to the plant exhausters.

Considering the large temperature differential between the discharge of the forward and aft nozzles, the collector system was designed to allow the inner wall to expand more than the outer wall. This was accomplished by supporting the inner wall at midpoint along its length, allowing the inner wall to expand toward the top and bottom of the duct, causing the end plates to flex. The collector system was fabricated of carbon steel with the exception of the inner wall which was 304 stainless steel. All-welded construction was employed.

Aft of the engine, a triangular area at the top and bottom of the gas collector system was exposed to the cell. It was anticipated that cell ambient temperatures might exceed limits caused by recirculation from these openings. Closure plates were designed and fabricated prior to engine installation.

Figures 2 through 5 show different views of the test vehicle and collector duct installation in the 3E test cell, with the closure plates attached.

3. Test Stand and Inlet Duct

The engine test stand was fabricated of structural steel. All-welded construction was employed except for the cold nozzle mounting structure which was bolted to the main test stand. This was done to facilitate installation and removal of the engine.

The inlet air system was of conventional design, consisting of a bulkhead-mounted bellmouth, labyrinth seal and engine-attached ducting.

4. Instrumentation

The exhaust collector duct instrumentation which was utilized for the altitude test program is shown in Figure 6. This instrumentation proved reliable during the test program and presented no special problems.

Test cell ambient pressures were measured using a set of three lip statics on each of the four engine exhaust nozzles. Some engine internal pressures and temperatures were recorded and additional parameters were calculated in order to verify that engine characteristics were not affected due to a possible aerodynamic coupling between the engine and exhaust collector ducting in the test cell.

Thermocouples were located at five axial locations on the starboard side and were checked with a single thermocouple on the port side collector duct. Four lip-static pressures were mounted on the exhaust duct inlet starboard side and one lip static on the port side. Four lip static pressures were also placed at the exhaust duct discharge, at the collector duct exit.

5. Test Vehicle

The engine chosen as the test vehicle to check out the altitude chamber modifications and work out the problems associated with testing a V/STOL engine was the F402-RR-402B vectored-thrust turbofan. This V/STOL engine has four exhaust nozzles. The two forward nozzles discharge fan air and the gas generator discharges through the two rear nozzles. The nozzles can be rotated from a horizontal position, providing thrust as in a conventional aircraft, to a downward vertical position to provide lift for a vertical takeoff or landing. Engine operation in the 3E altitude chamber was with the exhaust nozzles locked in the horizontal mode.

The compressor sixth and eighth-stage bleed systems used on the engine consisted of stainless steel tubing, expansion joints (designed to prevent structural loads on the engine), orifices to measure airflow, and control valves. Both bleed systems discharged aft of the engine. The discharge flow was directed at a right angle to the engine centerline to prevent interaction with the engine thrust measurement.

6. Altitude Chamber 3E Characteristics

The 3E altitude chamber capabilities allow performance to be evaluated throughout the entire operating envelope for any existing large Navy turbojet/turbofan engine or those planned for future applications. The chamber dimensions are a length of 9.1m(30 ft) and a diameter of 5.2m(17 ft). It has a hydraulically operated clamshell-type door. Maximum test cell capabilities in terms of individual parameters are indicated below. It should be noted that a condition of maximum Mn with maximum airflow is not obtainable.

Airflow kg/s(lb/sec)		318	(700)
Inlet Temp. °C(°F)	Cold	-54	(-65)
	Hot	344	(650)
Mach Number		3.0	(3.0)
Altitude m(ft)		30,500	(100,000)
Test Area	Length m(ft)	9.1	(30)
	Width/diameter m(ft)	5.2	(17)

The schematic of Figure 7 shows the 3E altitude chamber variable exhaust ejector/diffuser. Through the use of variable geometry equipment, altitude testing capability can be enhanced and performed with greater efficiency and flexibility.

The engine thrust stand is supported by four long steel rods mounted to the top of the chamber. Engine thrust is measured by two strain-gauge type load cells positioned under the center of the thrust stand. One load cell is used to apply a preload force when engine thrust is low, so that positive thrust readings are obtained at all times.

B. OPERATIONAL RESULTS

1. Steady-State Engine Calibrations

Steady-state engine calibrations were run from low to high power with the exhaust nozzles in the horizontal mode. At selected Power Lever Angle (PLA) conditions, multiple data points were recorded. The data verified that a stable, steady environment was maintained in the altitude chamber, and engine operating parameters were not affected. Parameters measured included engine airflow, fuel flow, thrust, turbine discharge temperature, gas generator pressures and temperatures, and exhaust nozzle pressures. Thrust specific fuel consumption was calculated from the measured thrust and fuel flow.

Test cell ambient temperatures during the altitude test were high due to engine exhaust gas recirculation. At times, thrust cell skin temperatures reached 107°C(225°F). The cooling method utilized initially was a conventional environmental enclosure around each load cell with

shop air forced through the enclosures. This method was inadequate, so additional cooling air was provided with little improvement shown during the limited operating periods. Thrust cell skin temperatures rose to well above the limit of 43°C(110°F); often as high as 82°C(180°F).

Thermocouples located in the area around the load cell indicated that the high temperatures were due to heat which was conducted to the thrust cell by its rear mount and the main frame of the test bed. For future installations, a more efficient method will be designed. Heat-insulating material will be located between the thrust cell and its rear support.

A post-test calibration of the thrust load cell was made at several temperatures to determine the effects of high ambient temperatures. The data showed the post-test calibration deviation from the original thrust calibration to be small. The worst-case error was approximately ±0.45% of 89,000N(20,000 lbs) full-scale; that is ±400N(±90 lbs).

Engine parameters recorded during the steady-state calibrations were used to estimate the accuracy of the data at various flight conditions over a range of power settings.

The F402 data base was analyzed by using the mathematical and statistical techniques given in references 4 and 5. The inputs to this analysis were the measurand accuracies, given in Table I, Measurand Accuracy Summary, and the F402 data base. The outputs of the accuracy analysis are summarized in Figures 8 through 10, where the engine parameters of airflow, net thrust, and thrust specific fuel consumption are plotted against uncertainty percent of value. These figures show error bands about the engine parameter values. The uncertainty quoted is the maximum expected error of the parameter. All of the engine test data fell within the error bands shown on the uncertainty plots.

TABLE I

MEASURAND ACCURACY SUMMARY

			Uncertainty	
Pressures				
Range	Bias	Precision	(psi)	(% f.s.)
7.5 psid	±.005 psi	±.002 psi	±.009	±.12
25 psia	±.01 psi	±.004 psi	±.019	±.076
60 psia	±.053 psi	±.034 psi	±.121	±.20
Thrust	(LBS)	(LBS)	(LBS)	(% f.s.)
20000 lbs	±16	±17	±50	±.25
Thrust Preload				
5000 lbs	±4	±4.5	±13	±.25
Fuel Flow	(PPH)	(PPH)	(PPH)	(% f.s.)
15000 pph	±6	±7	±20	±.13
Temperature			(°F)	
400°F	-	-	±2	
2000°F	-	-	±5	
Rotor Speeds			(RPM)	(% f.s.)
N_1 0-8400RPM	-	-	±1.5	±.018
N_2 0-14000RPM	-	-	±2.6	±.018

WHERE: Bias is the constant or systematic error.

Precision is the variation demonstrated by repeated measurements. Standard deviation is used as a measure of precision.

Uncertainty is an expression of a reasonable limit for the largest error expected. Uncertainty is equal to the Bias plus a multiple of the Precision. The multiplier decreases to a value of 2.0 as the number of samples used increases.

2. Engine Transients

Various types of engine transients were conducted. These included accelerations, decelerations and an accel-decel maneuver. Engine relights at altitude conditions were also performed, where the engine was stabilized at idle power, then shut off, and an attempted relight made a few seconds later. The primary concern was whether the simulated altitude environment could be maintained steady during the engine transients.

Figures 11 and 12 show an engine acceleration and deceleration at sea level static conditions and Figures 13 and 14 illustrate an accel and an accel/decel maneuver at an altitude environment of 6,100m(20,000 ft), 0.8 M_N. Engine parameters presented as a function of time are power lever position (PLA), low and high compressor rotor speeds (N_L, N_H), turbine discharge temperature (T_{t6}), fuel flow (W_{f1}, W_{f2}), burner pressure (P_b), variable inlet guide vane position (VIGV), high compressor discharge pressure (P_{t3}), and compressor inlet pressure (P_{t2}). The variation of P_{t2} during transients for several flight conditions is shown separately on Figure 15. The fluctuation of P_{t2} during engine transients is an indication of response capability of the facility air supply system to adjust to rapid changes in engine airflow. The plots shown are typical and indicate a rapid adjustment to an airflow change. A maximum pressure change of approximately 12kPa(3.5 inHgA) was observed, lasting for five seconds before returning to the value of the desired flight condition. This small pressure change of short duration had no adverse effect on engine operation, and will be less with new inlet controller circuits.

3. Simulated Altitude Environment Capability

Figure 16 shows the F402 operating envelope with the NAPTC facilities capability indicated. Presented is a curve of demonstrated plant exhauster capacity superimposed on the F402-RR-402 envelope. Three separate areas are defined. Area "A" denoted satisfactory engine operation with no limitations. Area "B" operation was possible with some electrical overload on the plant exhauster equipment. The "A" and "B" areas are separated by the 3E mechanical exhauster capacity schedule, assuming no additional pressure recovery. In general, an electrical overload during operation in area "B" occurred only at the higher power settings. Operation at lower power settings posed no problem. Engine operation in area "C" was not possible without severe electrical overload, even at power settings just above idle. Operation in this region could result in catastrophic equipment failure. Attempts to run in this region were aborted. The operational limit line was defined from 15,250m(50,000 ft) at 0.8Mn to 11,280m(37,000 ft) at 1.2 Mn.

A greater plant altitude/mach number capability than the 3E mechanical exhaust capacity line of Figure 16 was demonstrated during the facilities check-out program of the F402/exhaust gas collector duct system. The exhaust gas collector, because of its unique geometry, was not

designed for nor expected to produce significant pressure recovery. This doesn't mean that the exhaust collector/3E ejector system was not a contributing factor, but because there was little substantiating data to verify pressure recovery, it was assumed that most of the capacity extension was realized by running the exhausters in electrical overload. NAPTC has established that up to a 20% electrical overload is permissible for up to ten minutes operating time subject to changes in levels of equipment internal ambients. An alternate method of testing in regions "B" and "C" is to utilize choked nozzle techniques.

At the time of the test program, only two of the three combustion air refrigeration systems were available (the third system was being repaired). Consequently, inlet temperature was the primary inlet plant limitation. It was necessary to test some of the conditions at Hot Day temperatures instead of Standard Day temperatures. Had all three refrigeration systems been available, it is felt that all inlet temperature conditions would have been met.

All inlet air pressure and airflow conditions were met with the exception of 4,570m(15,000 ft), $1.2M_N$, which required 204kg/s(450 lb/sec) at 137kPa(40.6 inHgA). Unfortunately, there was not sufficient time at this condition for personnel to thoroughly check equipment and make adjustments which could yield higher header pressure. The opinion is that this condition can still be attained with four ram blowers.

The Facilities division recommended not using the No. 5 blower (axial flow) in parallel with the four centrifugal blowers until header pressure controls were installed. The controls were overdue at the time. When parallel operation is available, the 4,570m(15,000 ft), $1.2M_N$ test condition can be attained at steady-state satisfactorily. Transient operation will depend on how well the new controls perform.

Electric power consumption was significantly reduced as a result of extensive monitoring of plant electrical and mechanical performance. Equipment was run at optimum speeds and was shut down in a timely manner in the event of delays. A minimum of equipment was used during start-ups, cool-downs and warm-ups. Only when the engine and computer were ready was the full required equipment brought on line.

The choked-nozzle technique of attaining higher simulated altitude conditions was demonstrated during the engine check-out program. As long as the pressure ratio of front and rear nozzles is high enough and the flow is choked, the engine internal characteristics are not changed if the ambient pressure is changed. In a ducted installation in an altitude chamber, the inlet conditions are set for temperature and Mach number, while the exhaust pressure simulates ambient altitude pressure. In this test at 12,200m(40,000 ft), $0.8M_N$,

with choked flow at high power conditions, the exhaust pressure was lowered to approximately 9,750m(32,000 ft). Engine operation was stable. It should be noted that with this method, the thrust measurement would not be correct and must be accounted for. In Figure 16, where exact simulation was not possible without electrical overload, engine operation could still be checked by the choked-nozzle technique by setting the proper inlet conditions and lower altitude on the engine exhaust.

The 3E altitude chamber is equipped with a diffuser-ejector having a variable position centerbody capable of optimizing exhaust pressure recovery and minimizing exhauster operation costs. However, since the energy available from the test engine was low, attainable diffuser-ejector efficiency was also low; therefore, centerbody optimization was not sought. Figure 16 also shows the 3E exhauster capacity.

The most predominant factor affecting the 3E altitude chamber facility was the excessive cell temperatures during high power engine operation. Although there was no engine damage, some instruments and wiring had to be replaced, repaired or cooled differently in order to maintain proper functioning when peak temperatures were reached. Various steps were taken to overcome this problem.

Initially, the cell overtemperature alarm was activated as the engine fan (NL) speed approached 75% at sea level static conditions. Maximum cell cooling air was pumped into the cell at this time; however, all temperatures could not be controlled. Thermocouples located at various points around the exhaust duct showed that the highest temperature, 250°C(482°F), was in the region around the hot nozzle exhausts. This area was open to the cell on the top and bottom. Apparently, the hot nozzle exhaust gases were not completely captured and the excess spilled into the cell. In addition, radiation was suspected as contributing to the excessive cell temperatures. Therefore, the two triangular closure plates described above were installed to cover a major portion of the open exhaust area. These plates had been designed in anticipation of such a problem.

Considerable improvement was shown with the new configuration; however, an opening on the top and bottom, though smaller, still existed. Full power was attained but some temperatures were still as high as 200°C(392°F) which set off the overtemperature alarm. Cell cooling air was at maximum flow at this time. This created an additional problem in that the engine, at maximum power, already required near plant capacity airflow. Any cooling air requirement was an unfavorable burden. Another problem became evident during operation with this configuration; as power lever was increased, cell temperatures would increase almost instantaneously. However, when engine speed was decreased, cell temperatures decreased very slowly, particularly in the areas of the two closure plates which indicated that radiation was also a significant effect in addition to exhaust gas recirculation.

A final modification was implemented with the intent of minimizing the need for cell cooling air and maintaining lower cell temperatures. A partition was installed vertically between the two hot nozzles to help direct the exhaust streams and retard mixing and recirculation in the open area immediately downstream of the nozzle exhausts. In addition, an extension to the top closure plate was installed so that virtually no open area remained at the top. The area below this extension was obstructed with parts of the engine stand, and bleed piping which prevented the installation of a bottom extension. To minimize the primary source of radiation, the two original closure plates and the top extension were heavily insulated with block-type calcium silicate material and fiberglass cloth.

This last modification reduced cell ambient temperatures so that the highest recorded temperature anywhere in the cell did not exceed 125°C(257°F) at maximum engine power. For operation periods longer than five minutes, a small amount of cell cooling air was necessary. This maximum temperature was recorded at the remaining open areas at the top and bottom of closure plate leading edges; elsewhere, 100°C(212°F) was not exceeded, which is an acceptable cell ambient operating temperature. The only exception to this allowable temperature was the load cell skin temperatures which should not exceed 45°C(113°F).

Another item was the uneven exhaust pressure distribution around the individual nozzles. Initially, at 75% power, a significant difference 5.1kPa(1.5 inHgA) was shown between the average lip static pressures at the hot nozzles and the average at the cold nozzles. The cold nozzle pressures were lower and the hot nozzle pressures were near the desired altitude pressure. Seal plates were installed at each cold nozzle to minimize the gap between the nozzle lips and the collector ducts and subsequently reduce the secondary mass flow and velocity, since lower velocity around the cold nozzle would increase the nozzle lip static pressure. The seal plates reduced the differential to 2.5kPa(0.75 inHgA) at 75% and to less than 3.4kPa(1 inHgA) at maximum power. In addition to the hot/cold nozzle difference, the three pressures measured around the perimeter of each nozzle varied. This variation generally showed a depression on the outboard side of the cold nozzles and on the inboard side of the hot nozzles. The opposite sides of these depressions were exposed to large volumes of low velocity secondary airflow. Although improvement was shown, it would be more desirable to minimize these differentials even further. Utilizing the information obtained from the relatively short operating time, future engine installations will be improved upon in this area with minimal additional design effort.

During removal of the exhaust duct hardware, several weld cracks were discovered where the reinforcing struts were attached to the inner and outer walls of the cold nozzle exhaust ducts. These were fatigue failures primarily due to vibration.

C. IMPROVEMENTS TO ALTITUDE CHAMBER FACILITY DESIGN

Generally, it was established that NAPTC has the facility capability to operate and test vectored-thrust V/STOL engines such as the F402 in the horizontal thrust mode at altitude conditions. For future installations of similar engines, the same design approach would be utilized with some modifications.

The exhaust gas collector duct would be redesigned to provide sufficient pressure recovery to allow engine operation at high power in region "B" on Figure 16 without causing an electrical overload to the exhauster equipment, and perhaps also permit engine operation in region "C". Additional pressure recovery may be obtained with a modified collector duct in combination with an optimized position of the chamber diffuser-ejector plug.

One design goal which would be sought to further improve the cell ambient temperature effects is to enclose the hot nozzle exhaust gases even more and permanently insulate all outside exhaust duct walls. The load cell environmental enclosures would be water jacketed, and since the thrust load cell was shown to absorb conducting heat from the large structural I-beam mounting base, additional local cooling would be provided to this area.

An improved cold nozzle seal plate design should be incorporated to further reduce the nozzle-to-cell pressure differential. This could be accomplished by eccentrically varying the gap between the nozzles and seal plates.

Another improvement for the structural integrity of the exhaust duct system is to attach the struts retaining the inside and outside cold duct walls by means of bolts or rivets instead of welding.

D. PLANS FOR SEA LEVEL TEST CELL MODIFICATIONS

Work on the sea level program is currently in progress. Modifications will be made to the exhaust duct, thrust stand, load cell and test stand flexures. Instrumentation will also be updated. Provisions will be made to vector engine thrust and measure thrust components in both the horizontal and vertical directions. Verification of test cell modifications and facility operational capabilities will be made with an available V/STOL engine as the test vehicle.

A scale model of the exhaust gas collector duct system was designed and fabricated to check flow charactersitics before proceeding with construction of the full-scale collector duct. Model test results only slightly altered the final design of the collector duct system. One of the critical contraints in the sea level installation is the small distance available between the engine nozzle exhaust and the deck of the test cell; approximately 1.8m(6 ft). NAPTC is confident that the exhaust

collector duct system designed will allow the exhaust gases to be directed rearward out of the chamber without problems of recirculation or effect on thrust measurement. Test capability will be developed for a four-poster type engine and other candidate V/STOL propulsion systems. A report will also be prepared on the sea level program effort.

Plans call for operating the engine in a vectored thrust mode; i.e., with the nozzles operating in all positions from horizontal to vertical. The four nozzles will be ducted individually to the exhaust stack. When operating in the vertical mode, the exhaust gas is directed downward and the exhaust gas collectors must turn the exhaust to the exhaust stack at the rear of the cell. Aerodynamically designed turning vanes will be employed to accomplish this with minimum gas recirculation into the cell. At the Bristol Engine Division of Rolls-Royce, the engine was mounted 4m(13 ft) above the floor which allowed using a long radius turning duct for the exhaust gases. Simple turning vanes are adequate to turn the gas flow to the exhaust stacks. The RB193 lift/cruise engine with swivel nozzle for the VFW-Fokker VAK-191B aircraft was tested at MTU, Munich, Germany and installed with the engine centerline 2.8m(9.1 ft) above the ground plane. At NAPTC, the engine will be mounted 1.4m (4.6 ft) above the floor; therefore, the turning vanes must be aerodynamically shaped to accomplish effective redirection of the exhaust gases. High cell temperatures are not anticipated since the nozzles will discharge into individual exhaust gas ducts and the secondary airflow induced by the pumping action of the exhaust gas through the exhaust stack will keep the cell cool.

During the altitude test, cell ambient pressures were measured using a set of three lip statics on each of the four exhaust nozzles. Since the nozzles were locked in place (horizontal mode), no special problems were encountered. For the sea level test, the nozzles will be vectored; therefore, rigid stainless steel tubing cannot be used for the lines. Two approaches are possible:

a. Flexible nylon tubing can be utilized in the area where the twisting and the movement exist. This tubing is rated for a burst pressure of 2,760kPa(400 psi) at a temperature of 125°C(257°F) and should be suitable for use under the environmental conditions which will be encountered.

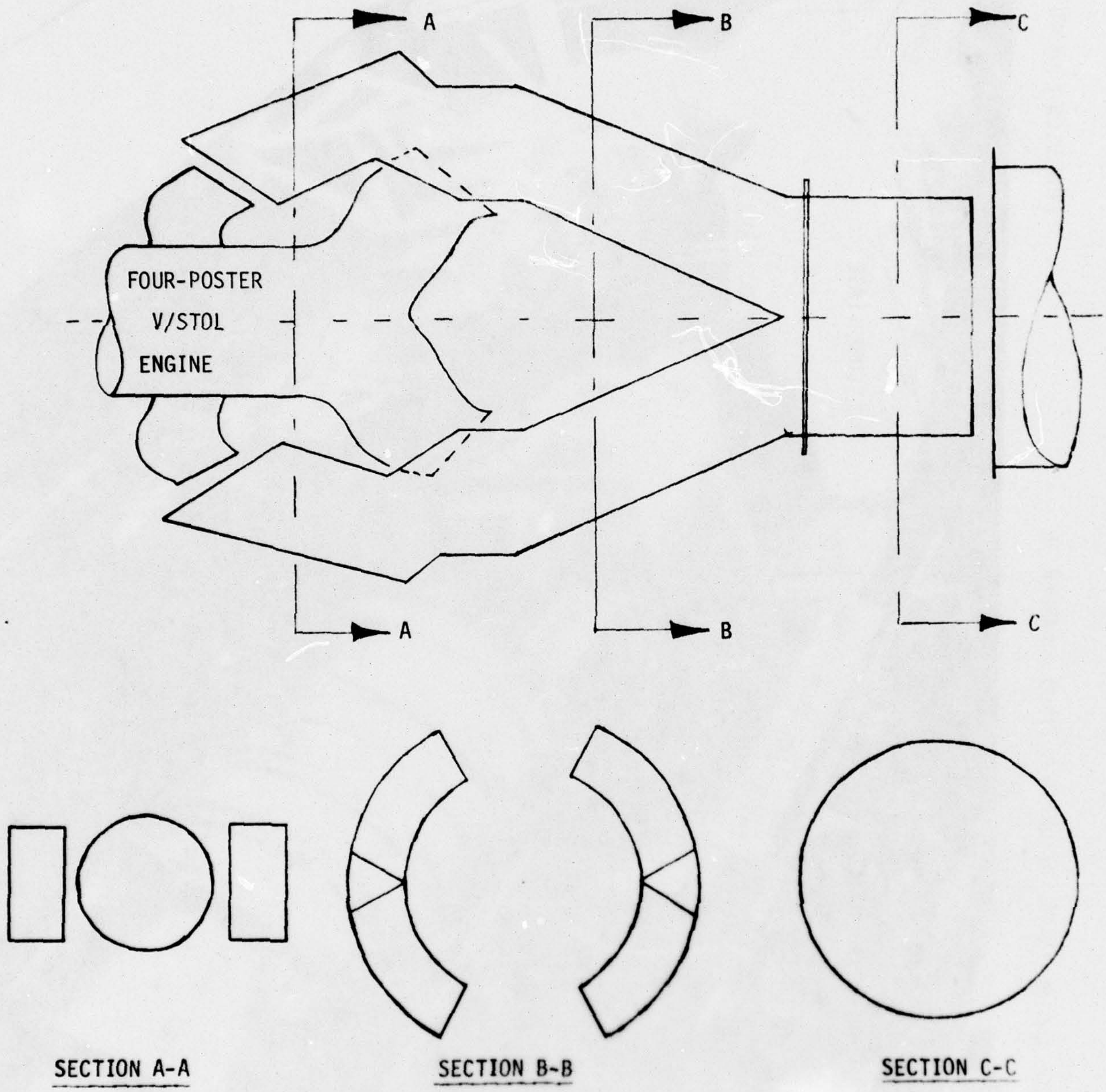
b. Basket statics can be used to measure cell ambient pressure in several locations; for example, near each of the four engine exhaust nozzles.

Successful completion of the altitude program established that NAPTC can test four-poster V/STOL engines, such as the F402, in the horizontal thrust mode at simulated altitude conditions. The sea level program will provide the capability to determine engine performance in both vertical and horizontal modes. Should fleet service problems occur with the AV-8A/F402 weapon system, NAPTC will be in a position to respond positively to determine a solution.

LIST OF SYMBOLS

Symbol	Definition	Units
MTU	Motoren und Turbinen Union, Munich, Germany	-
NAPTC	Naval Air Propulsion Test Center	-
NARF	Naval Air Rework Facility	-
NAVAIR	Naval Air Systems Command	-
NL	Fan Low Rotor Speed	rad/s(RPM)
NH	Compressor High Rotor Speed	rad/s(RPM)
PLA	Power Lever Angle	rad (degree)
Pt2	Compressor Inlet Total Pressure	kPa(inHgA)
Pt3	High Compressor Discharge Total Pressure	kPa(inHgA)
Pb	Burner Pressure	kPa(inHgA)
Ps14	Facility Exhauster Inlet Pressure	kPa(inHgA)
TSFC	Thrust Specific Fuel Consumption	mg/N·s(lb fuel/hr)/(lb thrust)
Tt6	Turbine Discharge Temperature	°C(°F)
VIGV	Variable Inlet Guide Vane Position	rad(degree)
V/STOL	Vertical/Short Takeoff and Landing	-
Wa	Total Airflow	kg/s(lb/sec)
Wf1, Wf2	Fuel Flow	kg/hr(lb/hr)

FIGURE 1: SCHEMATIC OF ENGINE EXHAUST GAS COLLECTOR DUCT SYSTEM



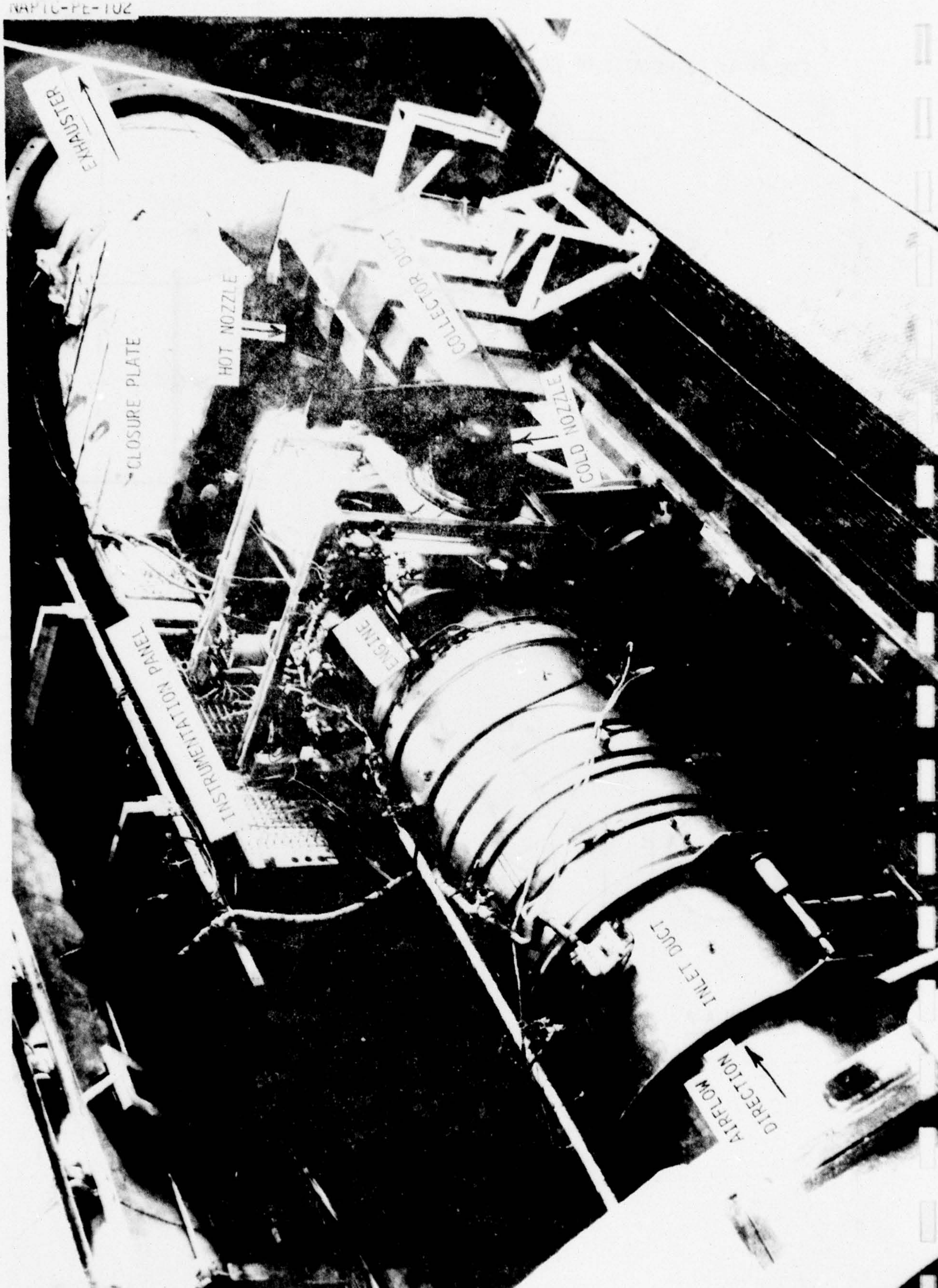


FIGURE 2: FOUR-POSTER V/STOL ENGINE INSTALLATION IN ALTITUDE CHAMBER 3E (TOP VIEW LOOKING AFT)

FIGURE 3: FOUR-POSTER V/STOL ENGINE INSTALLATION IN ALTITUDE CHAMBER 3E (SIDE VIEW LOOKING AFT)

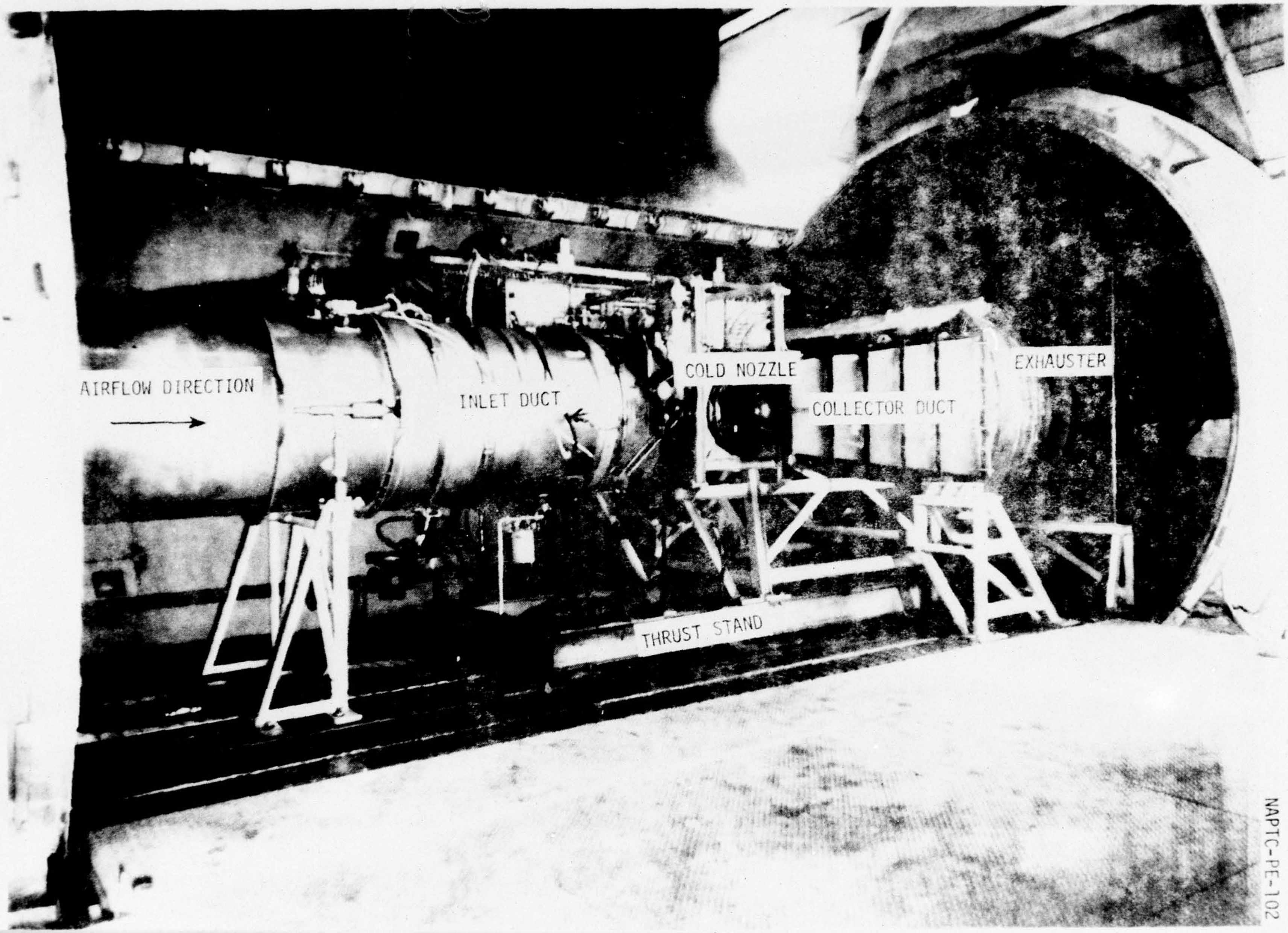
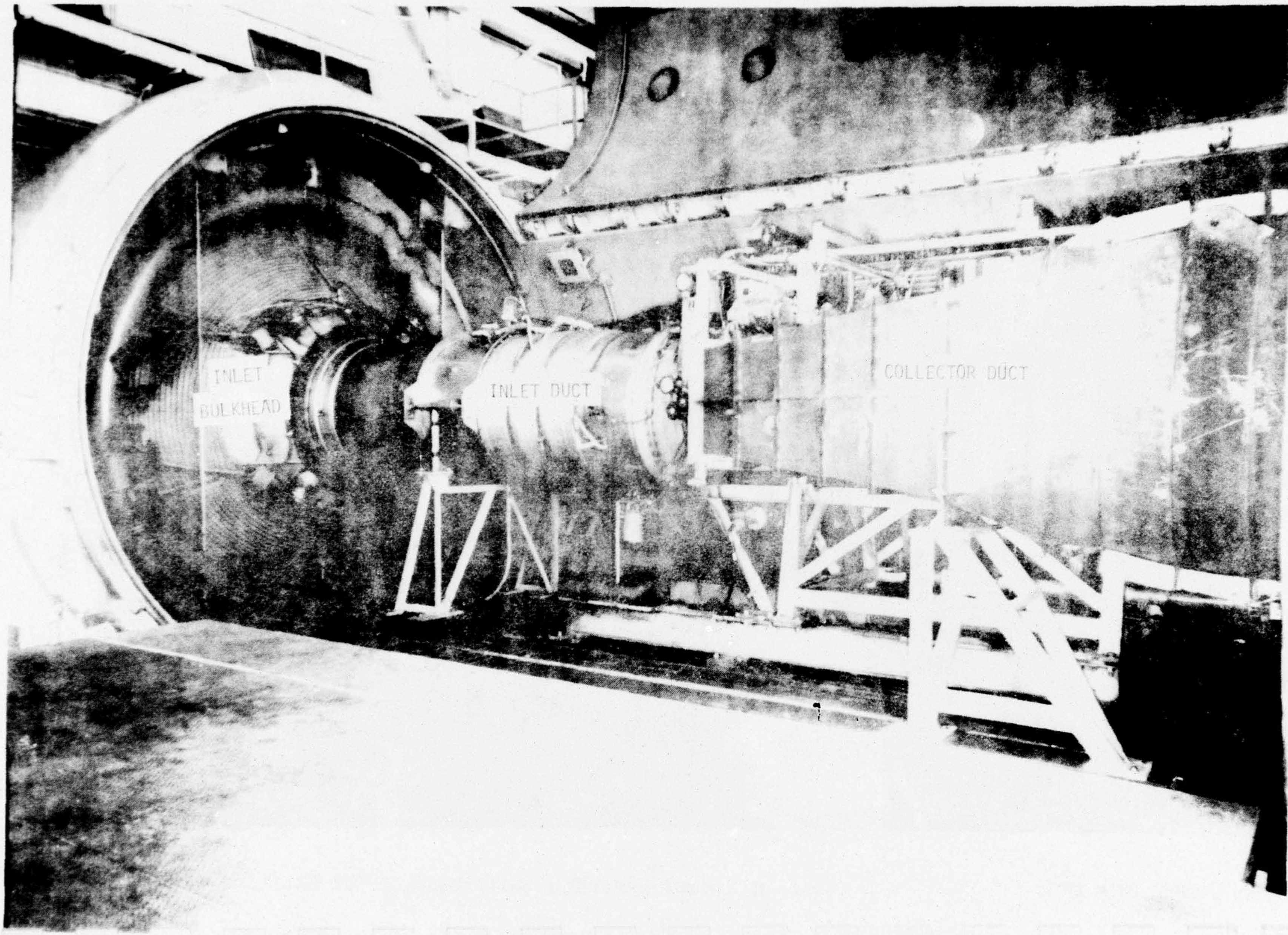


FIGURE 4: FOUR-POSTER V/STOL ENGINE INSTALLATION IN ALTITUDE CHAMBER 3E (SIDE VIEW LOOKING FORWARD)



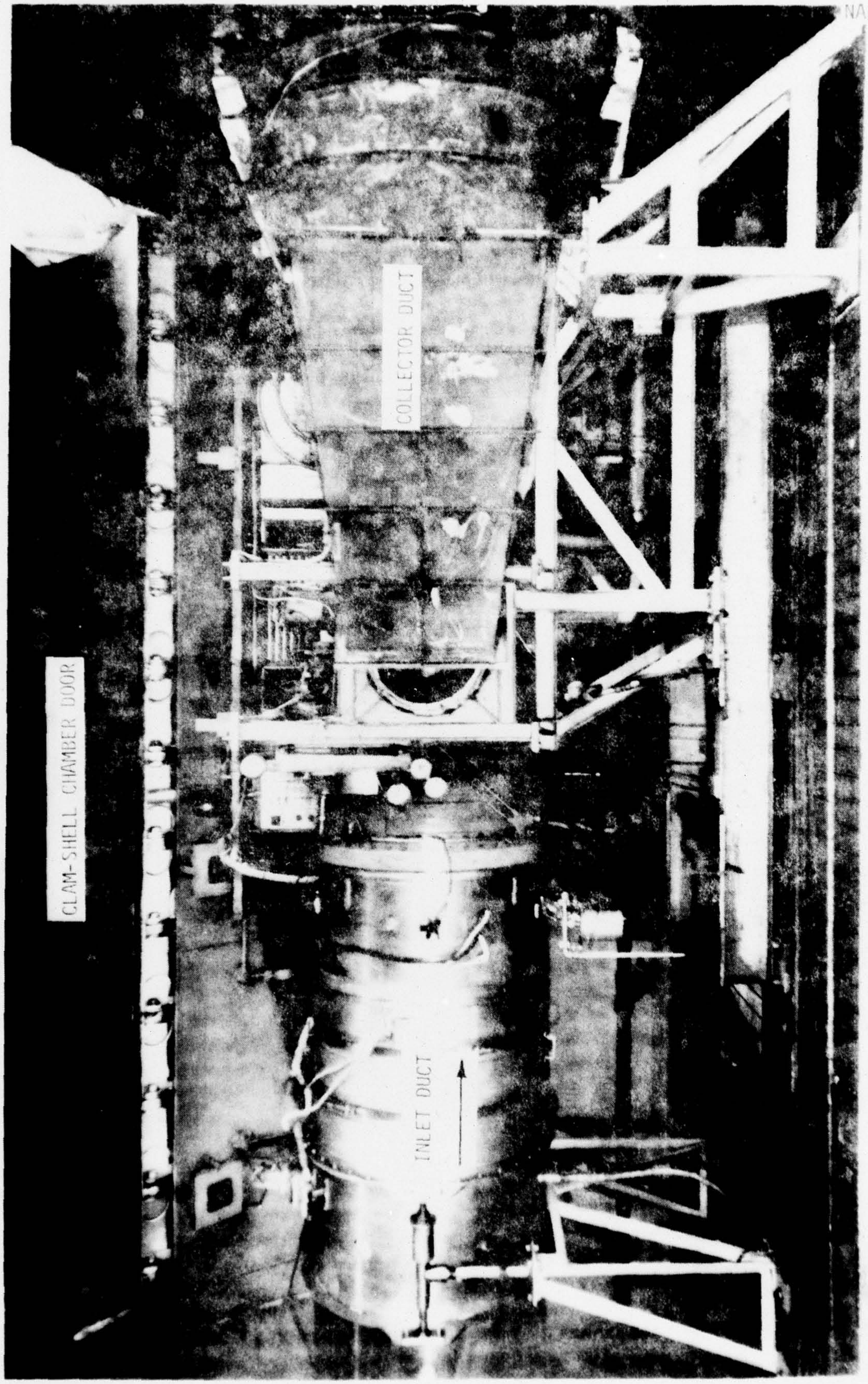


FIGURE 5: FOUR-POSTER V/STOL ENGINE INSTALLATION IN ALTITUDE CHAMBER 3E
(SIDE VIEW)

FIGURE 6: EXHAUST COLLECTOR DUCT INSTRUMENTATION

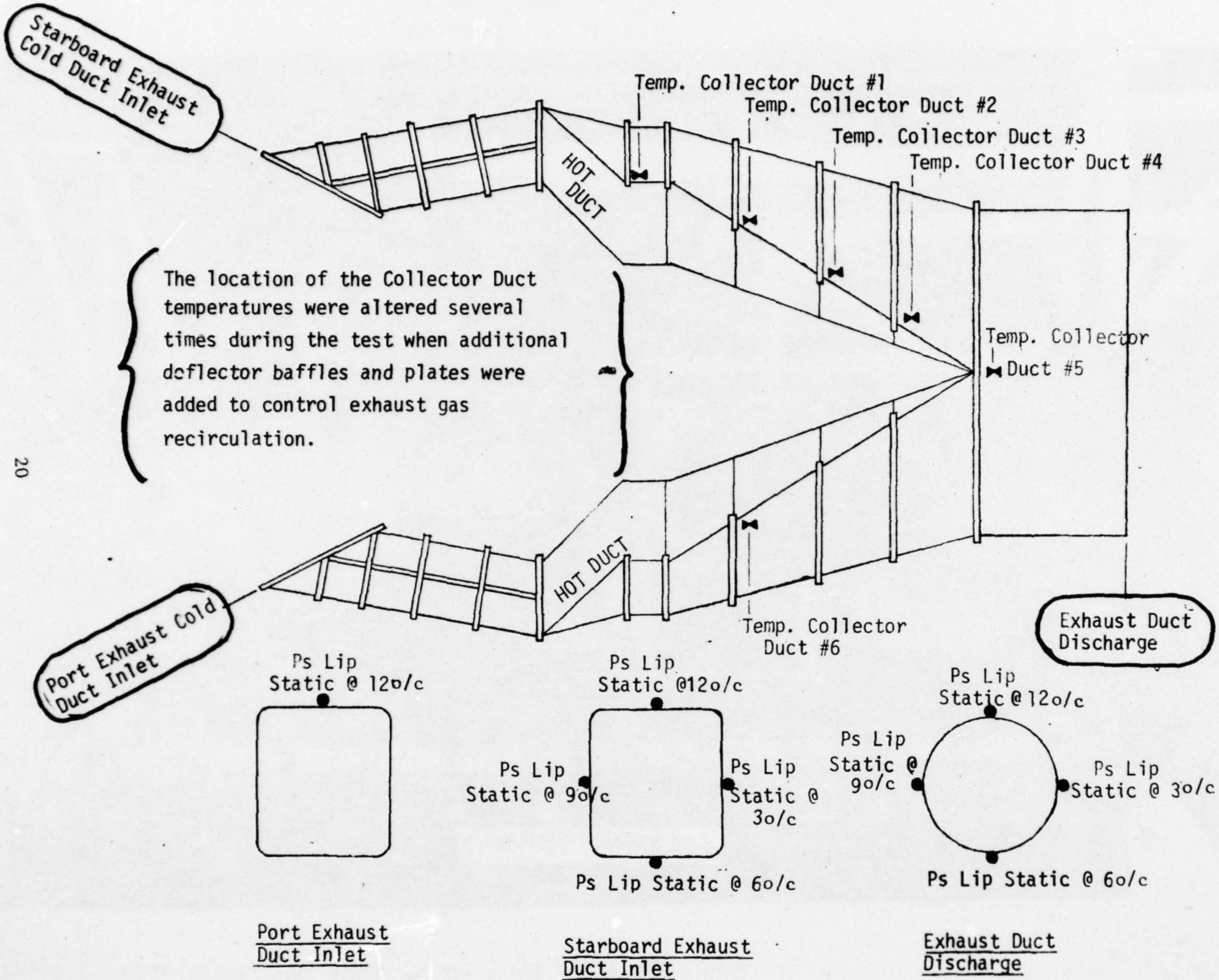
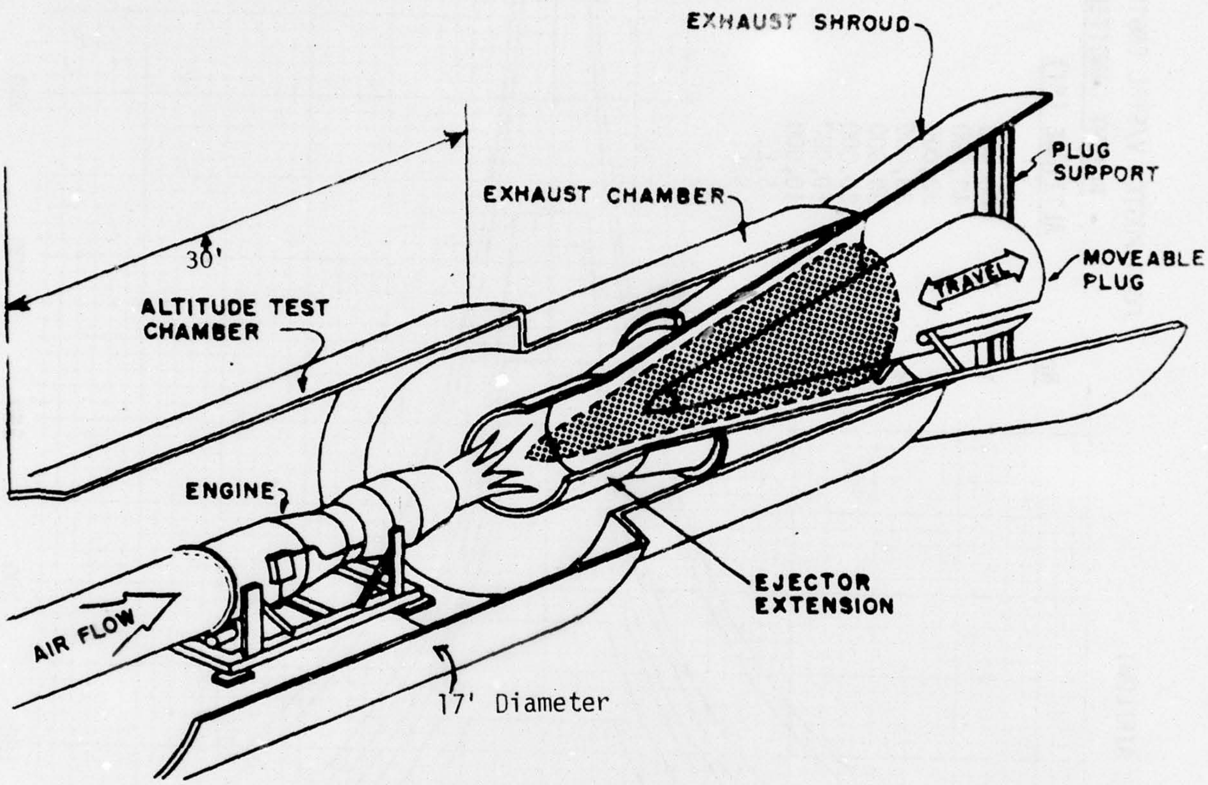


FIGURE 7: 3E ALTITUDE CHAMBER VARIABLE EXHAUST EJECTOR/DIFFUSER



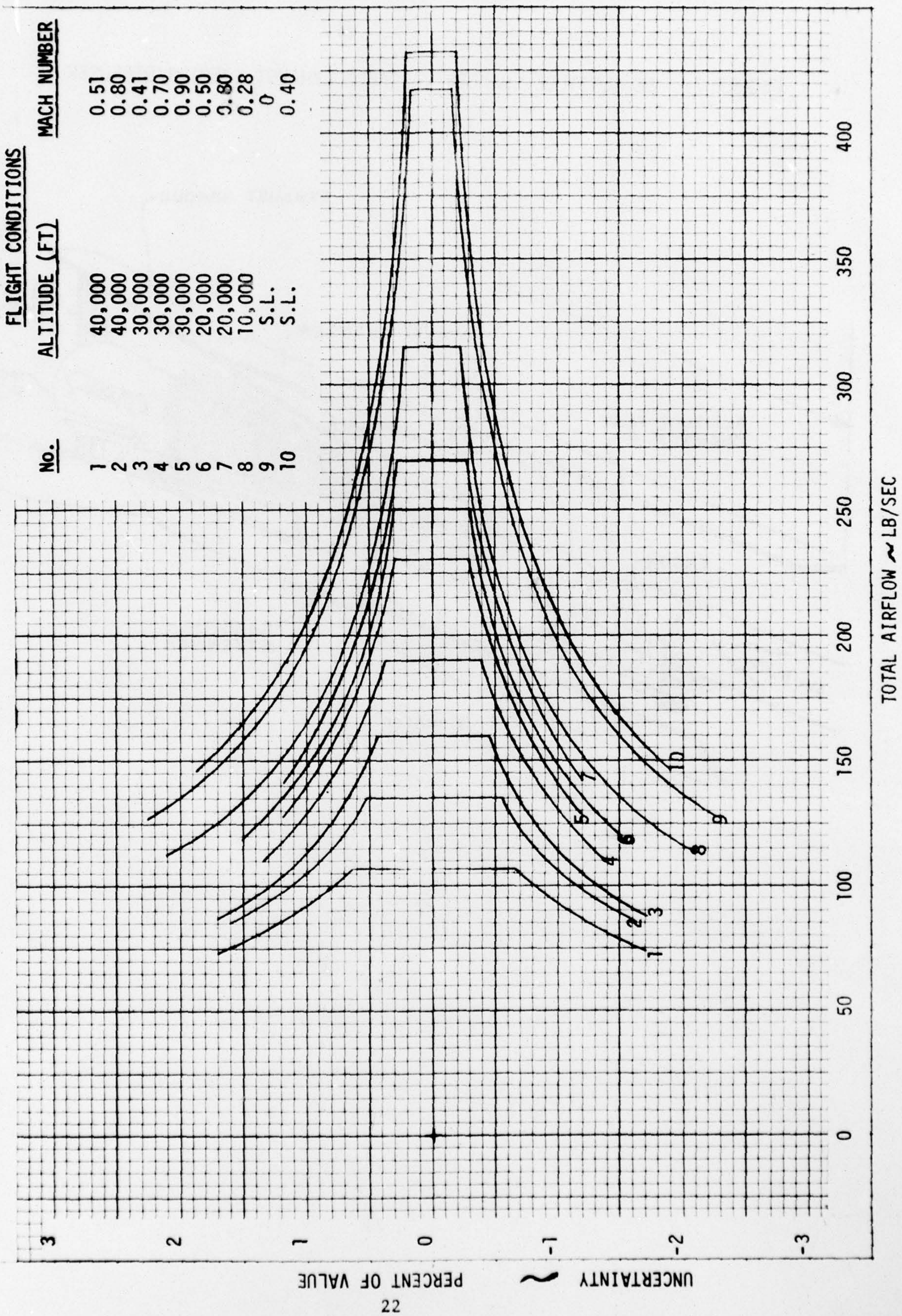


FIGURE 8: ACCURACY OF STEADY-STATE DATA (TOTAL AIRFLOW)

FIGURE 9: ACCURACY OF STEADY-STATE DATA (NET THRUST)

FOUR-POSTER V/STOL ENGINE

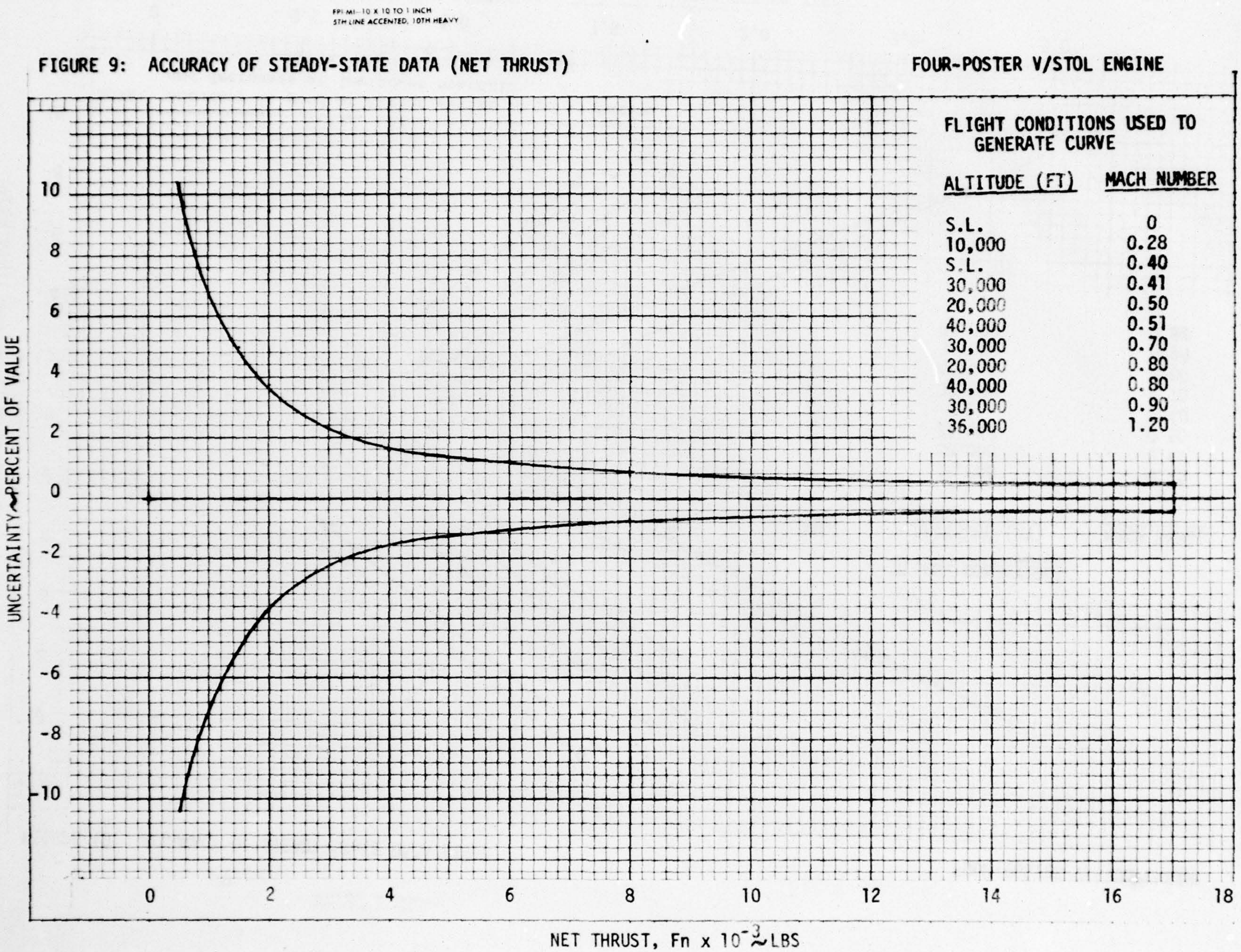


FIGURE 10: ACCURACY OF STEADY-STATE DATA (TSFC)

FOUR-POSTER V/STOL ENGINE

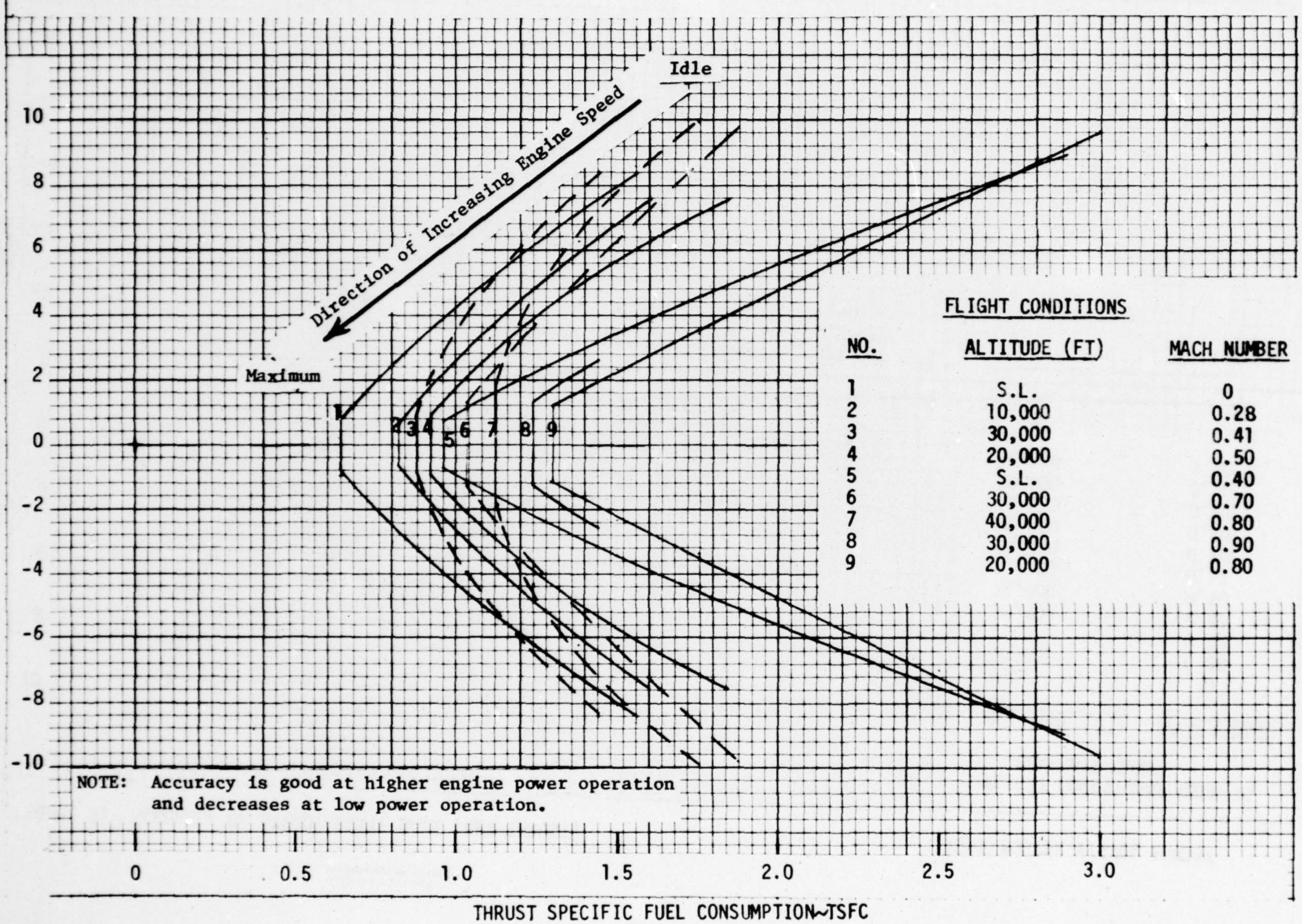
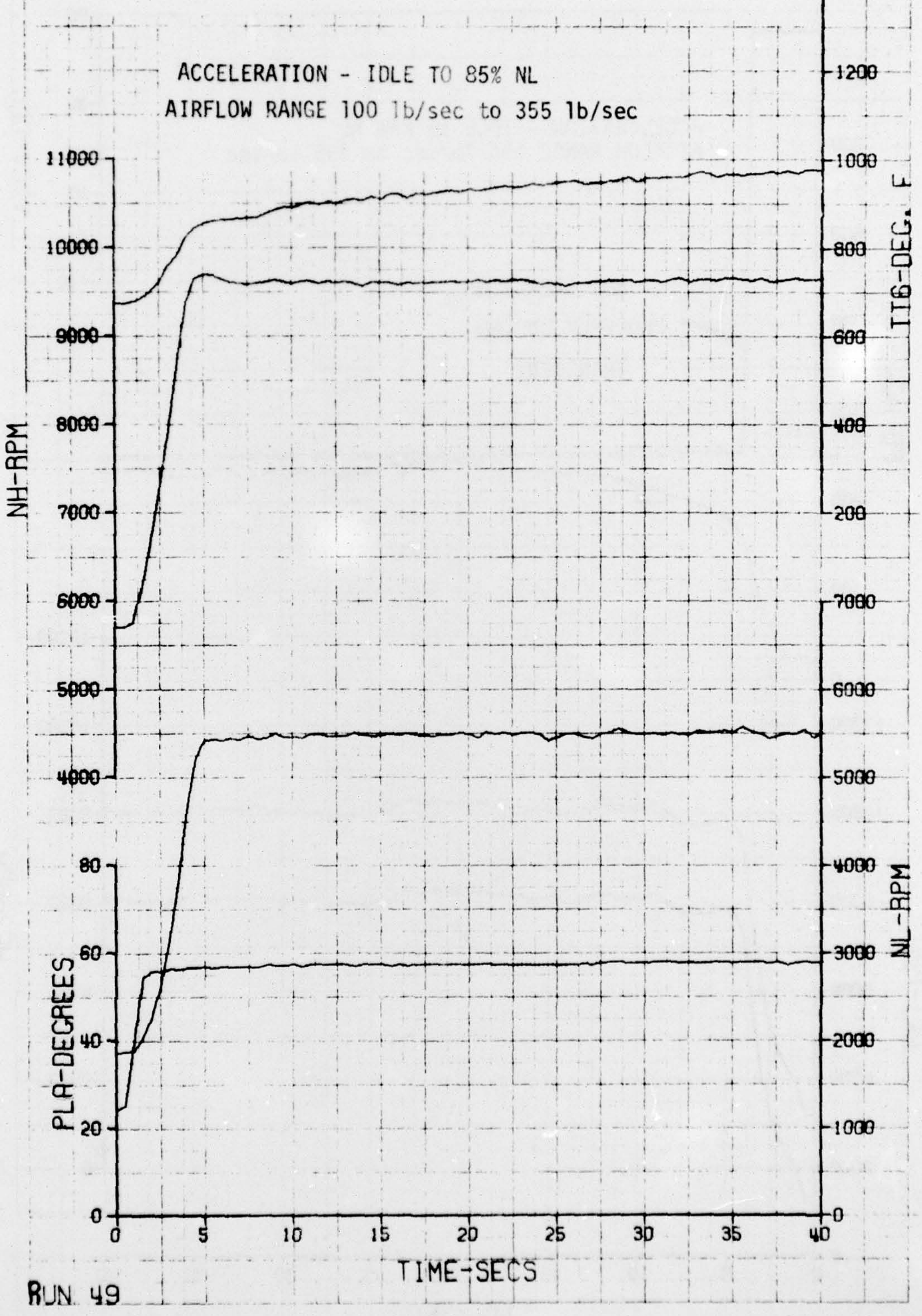


FIGURE 11: ENGINE ACCELERATION AT SIMULATED SEA LEVEL STATIC CONDITIONS



RUN 49

FIGURE 11a: ENGINE ACCELERATION AT SIMULATED SEA LEVEL STATIC CONDITIONS

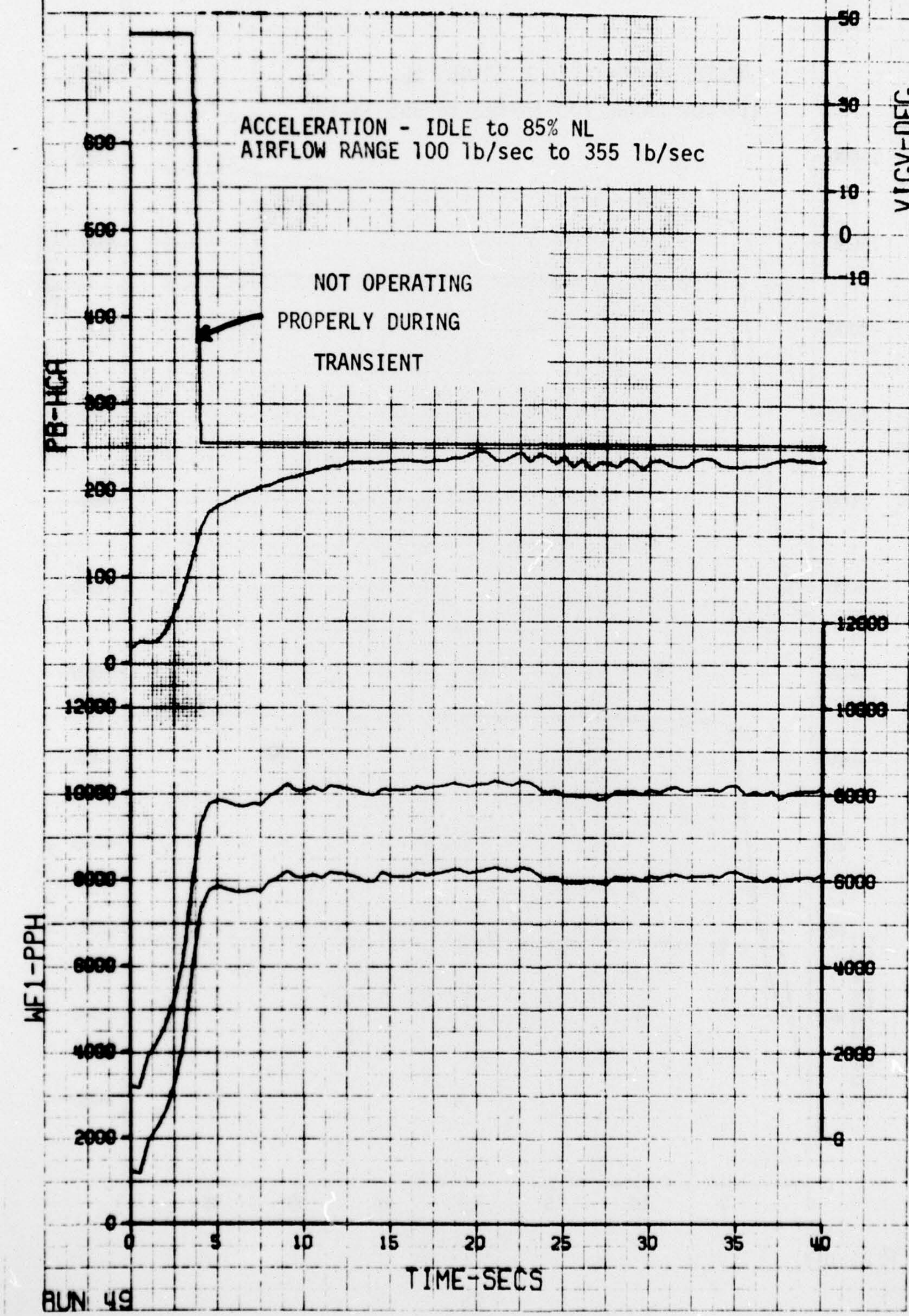


FIGURE 12: ENGINE DECELERATION AT SIMULATED SEA LEVEL STATIC CONDITIONS

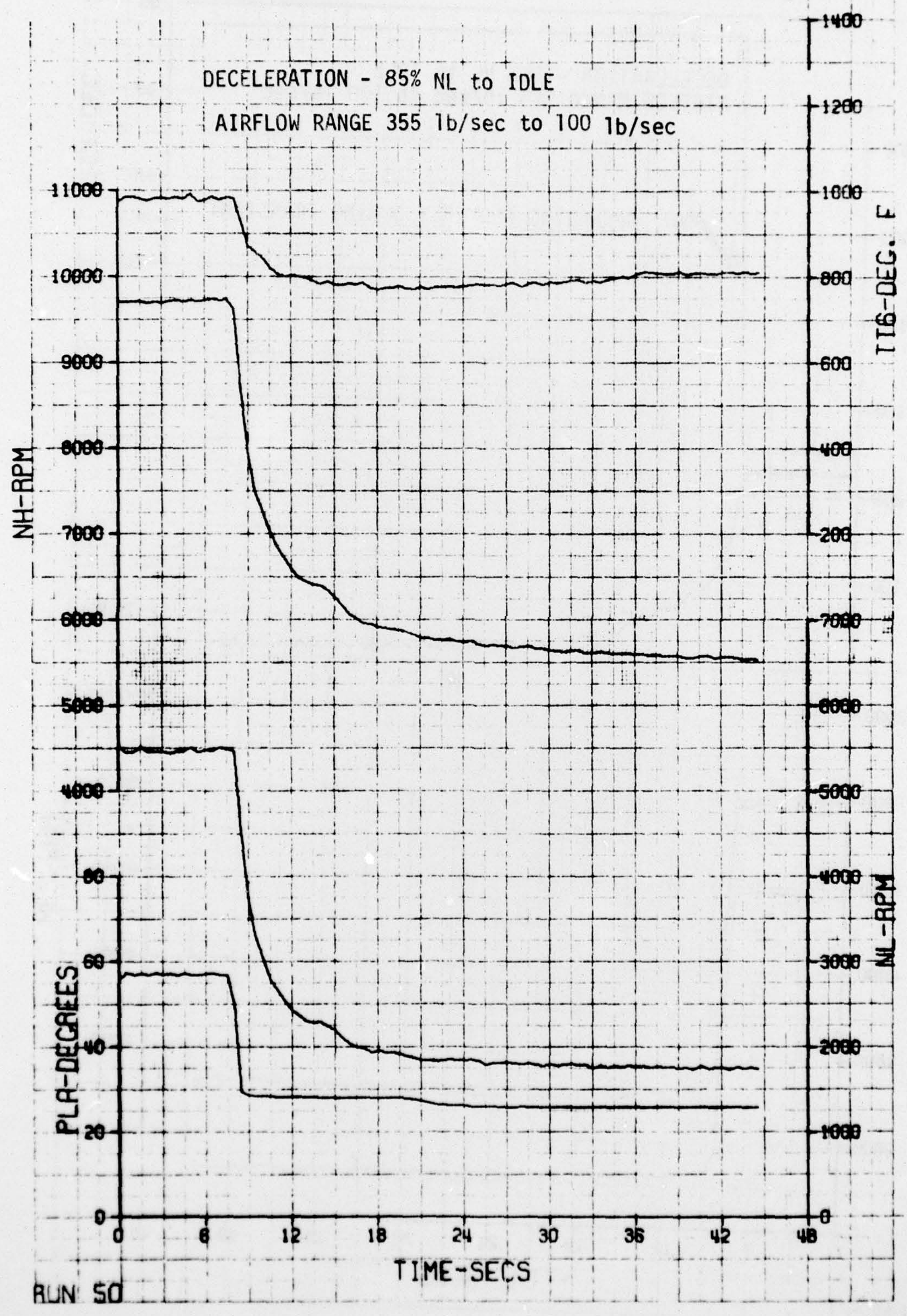


FIGURE 12a: ENGINE DECELERATION AT SIMULATED SEA LEVEL STATIC CONDITIONS

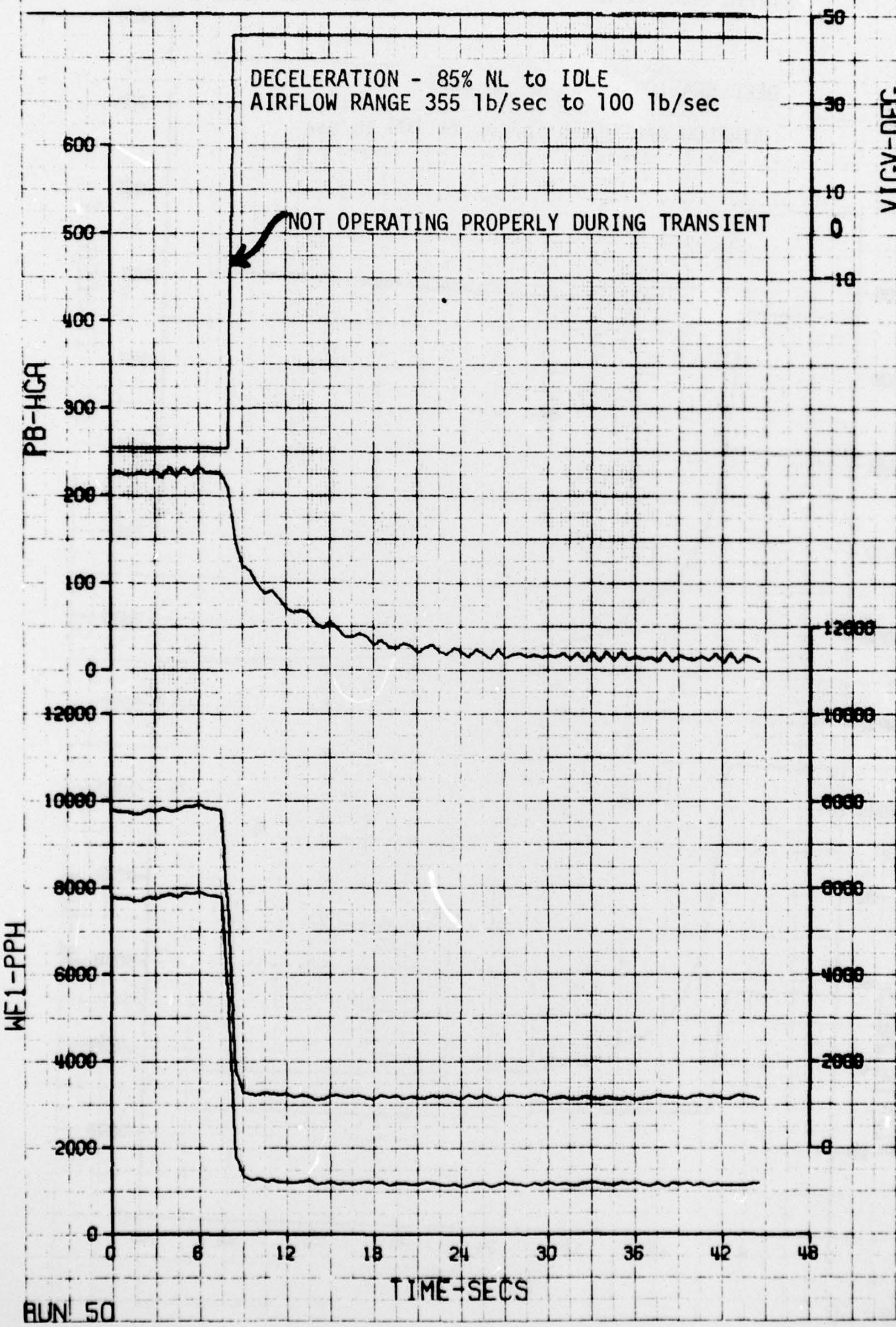


FIGURE 13: ENGINE ACCELERATION AT SIMULATED ALTITUDE FLIGHT ENVIRONMENT

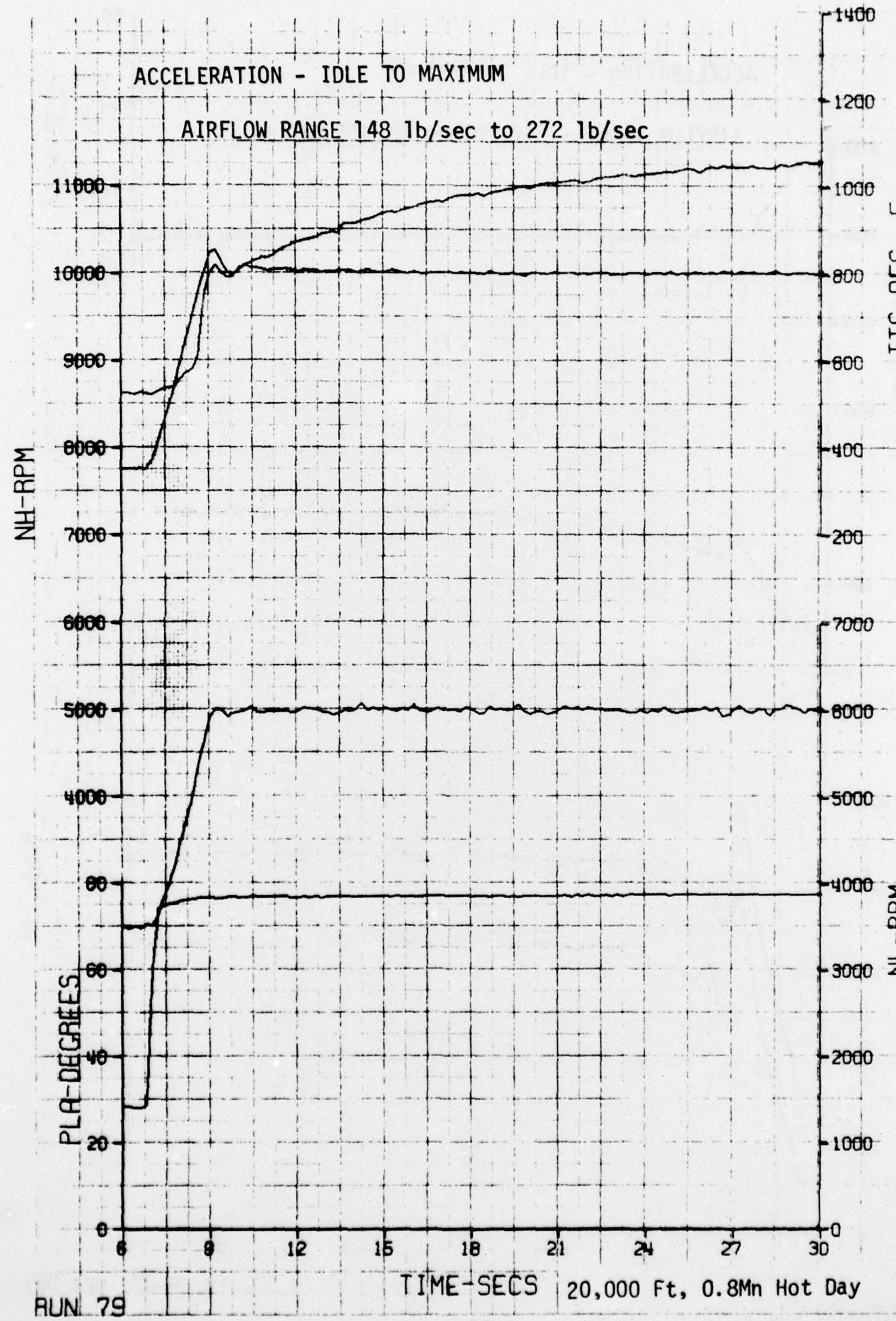


FIGURE 13a: ENGINE ACCELERATION AT SIMULATED ALTITUDE FLIGHT ENVIRONMENT

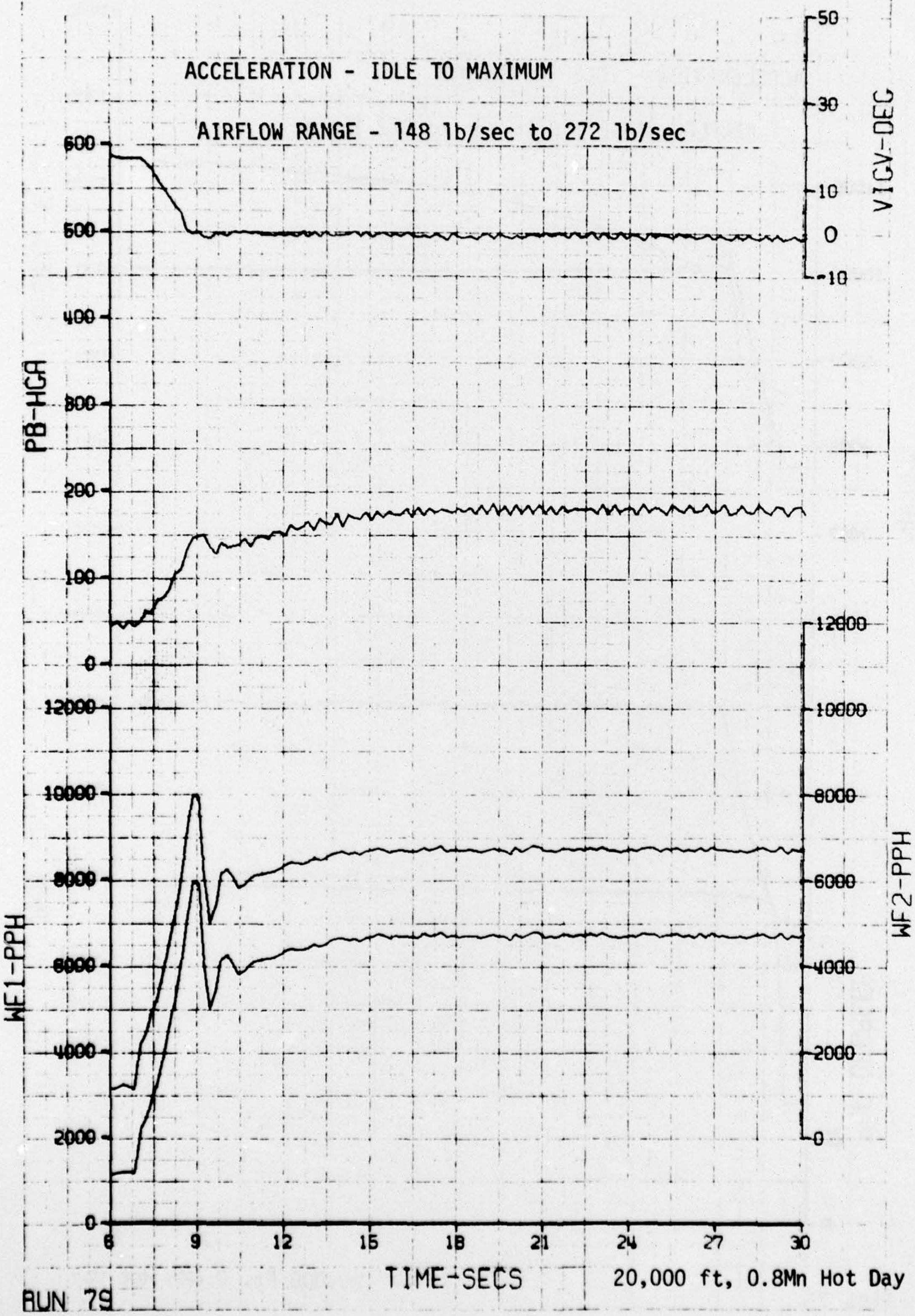


FIGURE 14: ENGINE ACCELERATION/DECELERATION MANEUVER AT SIMULATED ALTITUDE FLIGHT ENVIRONMENT

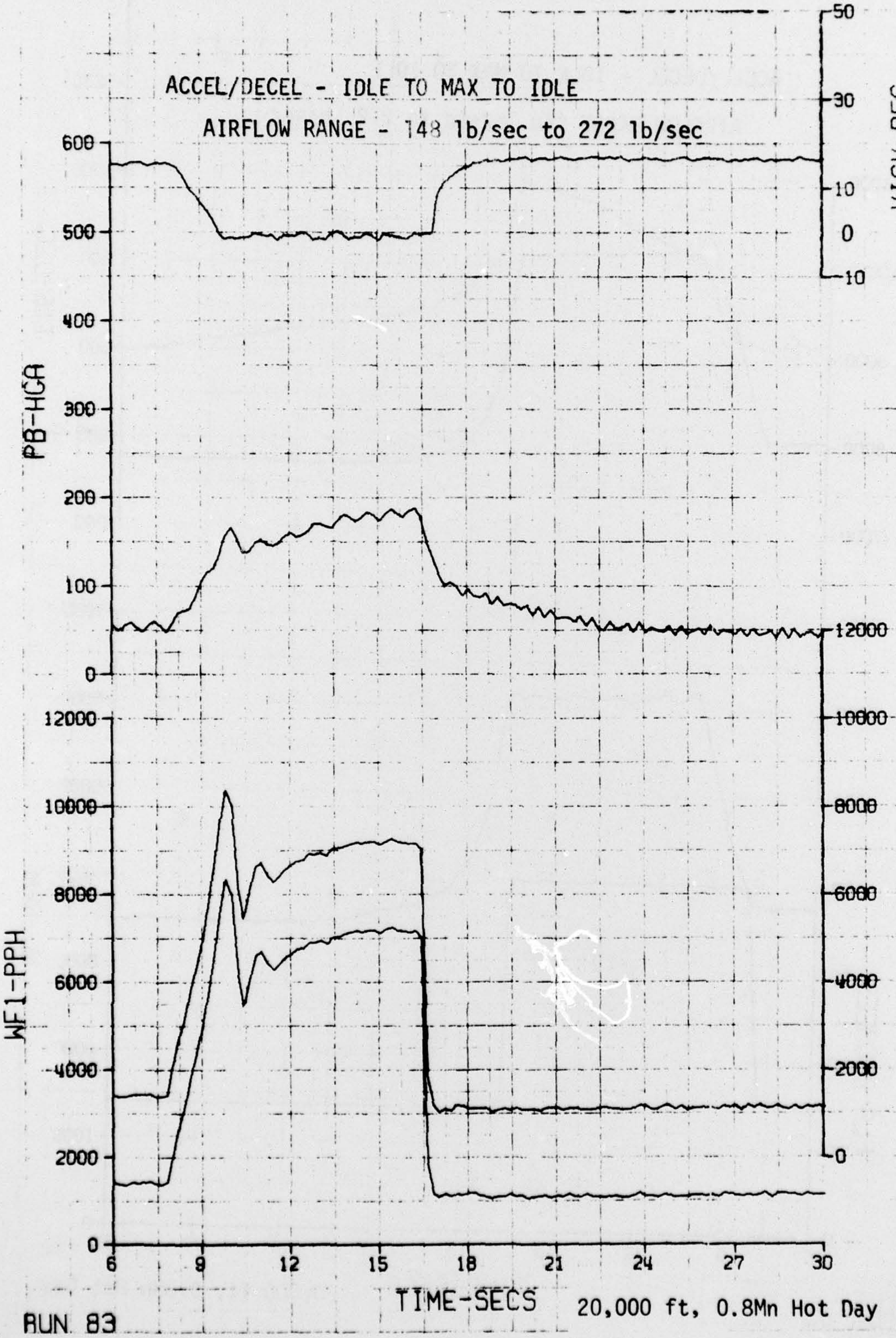
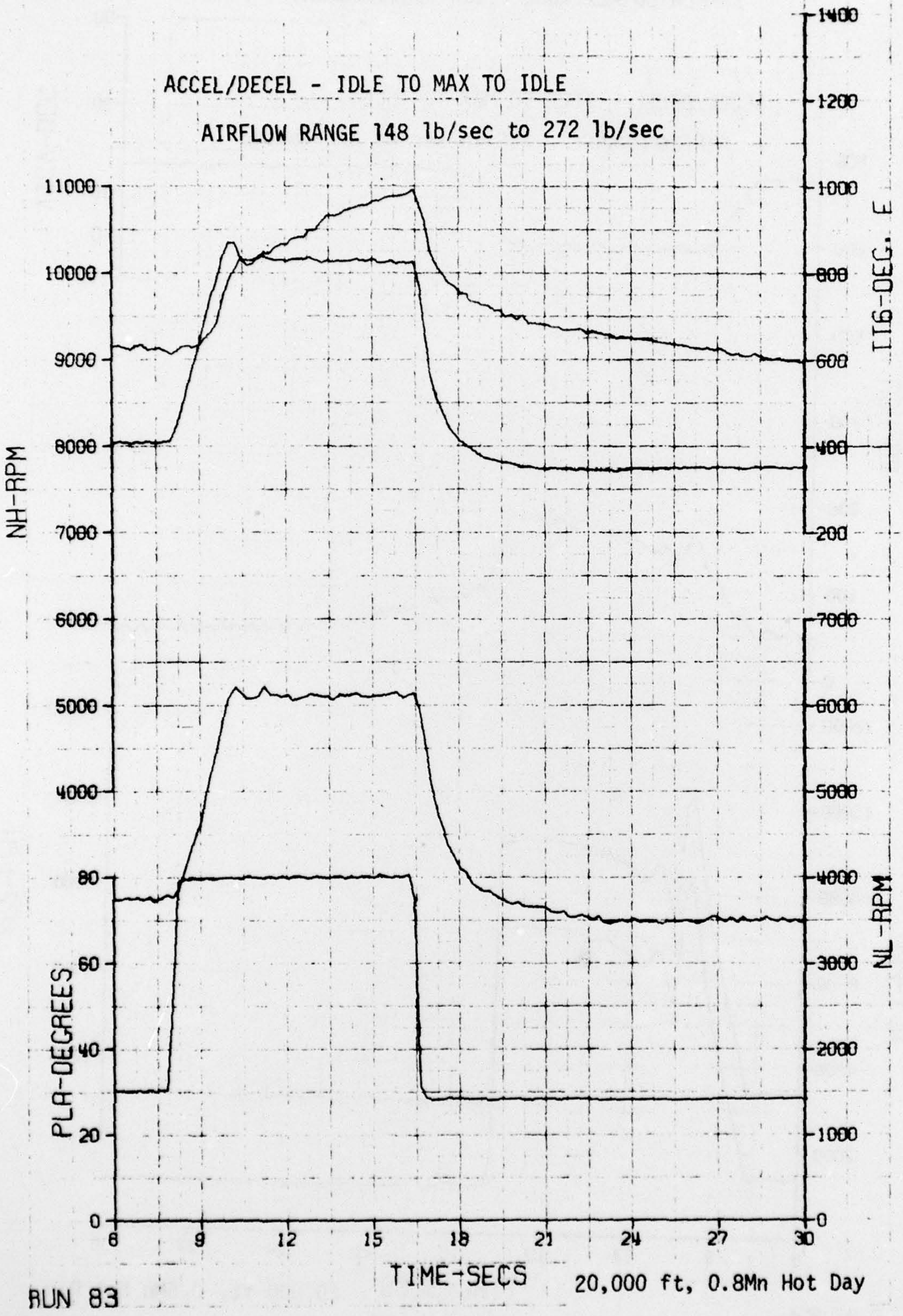


FIGURE 14a: ENGINE ACCELERATION/DECELERATION MANEUVER AT SIMULATED ALTITUDE FLIGHT ENVIRONMENT



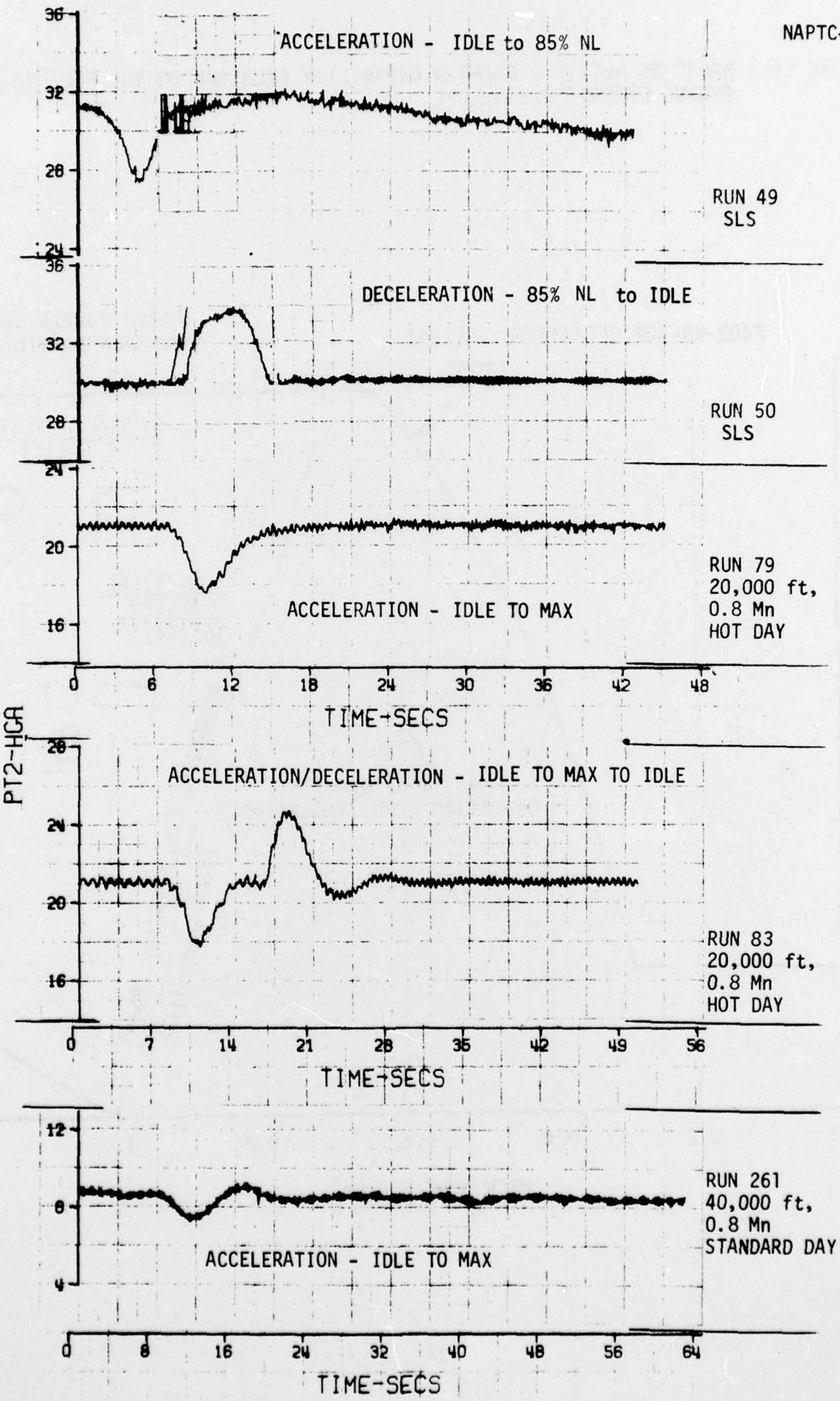
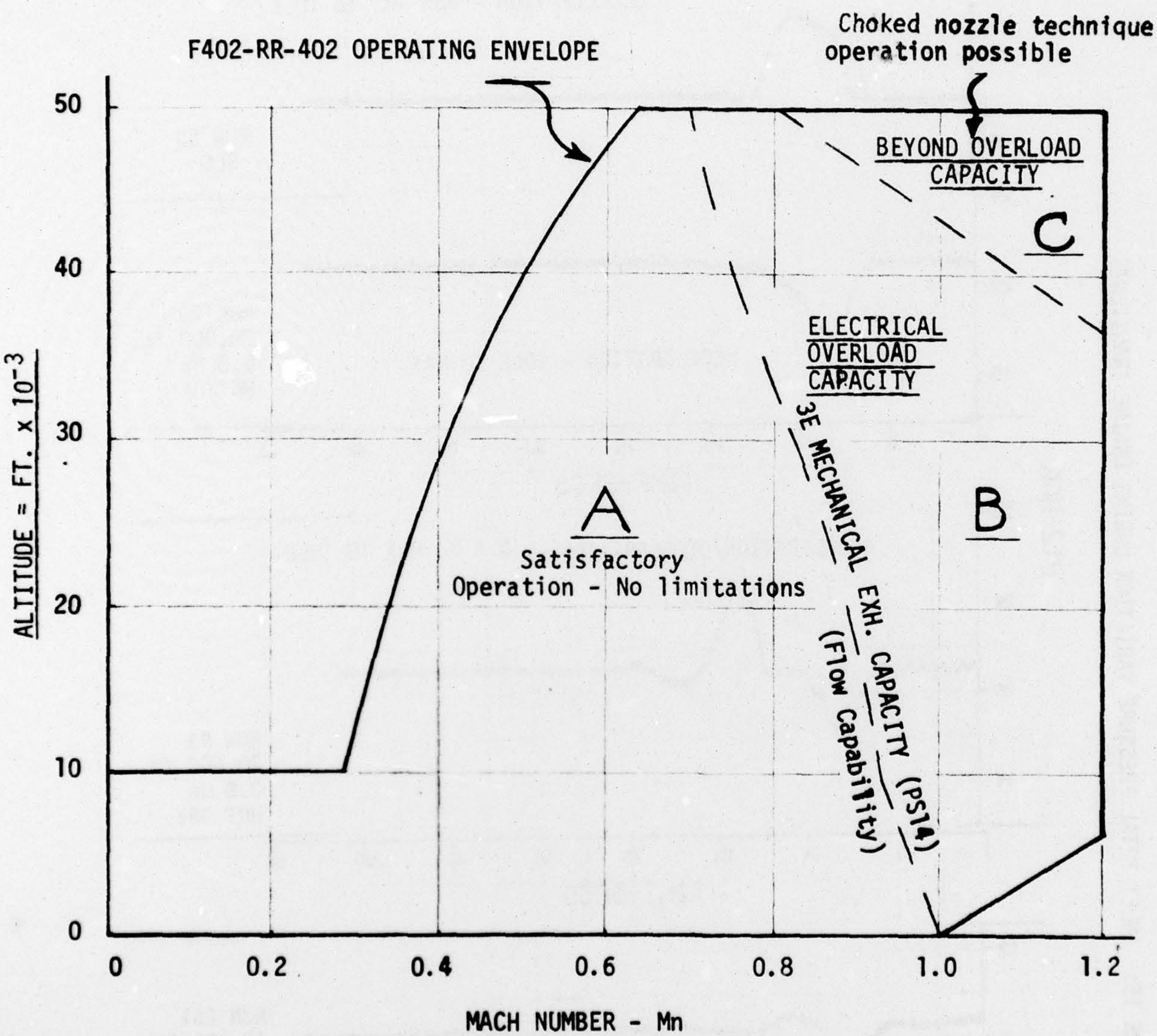


FIGURE 15: INLET TOTAL PRESSURE VARIATION DURING ENGINE TRANSIENTS

FIGURE 16: NAPTC 3E ALTITUDE CHAMBER CAPABILITY RELATIVE TO THE F402-RR-402 ENGINE OPERATING ENVELOPE



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